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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY-(PCT)

(51) International Patent Classification <sup>6</sup> : G06F 11/14	A1	(11) International Publication Number: WO 99/17201 (43) International Publication Date: 8 April 1999 (08.04.99)
(21) International Application Number: PCT/US98/20415 (22) International Filing Date: 30 September 1998 (30.09.98) (30) Priority Data: 08/941,478 30 September 1997 (30.09.97) US (71) Applicant: TANDEM COMPUTERS INCORPORATED [US/US]; 10435 North Tantau Avenue, Cupertino, CA 95014 (US). (72) Inventors: LENNIE, Robert; 1536 South Wolfe Road, Sun- nyvale, CA 94087 (US). JOHNSON, Charles, W.; 3954 Williams Road, San Jose, CA 95117 (US). (74) Agents: BENNETT, Robert, J. et al.; Townsend and Townsend and Crew LLP, 8th floor, Two Embarcadero Center, San Francisco, CA 94111-3834 (US).	(81) Designated States: JP, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).  Published <i>With international search report. Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</i>	
(54) Title: A FAULT TOLERANT METHOD OF MAINTAINING AND DISTRIBUTING CONFIGURATION INFORMATION IN A DISTRIBUTED PROCESSING SYSTEM  (57) Abstract  A computing system in the form of a cluster of a number of multiprocessing nodes maintains, in a fault tolerant manner, a distribution of configuration data for each of the nodes so that each node has a database containing the configuration data associated with that node. The database, and therefore, the configuration data it contains, associated with any one node is substantially identical to that of any other node. A process running on one of the nodes is responsible for receiving requests that require modification of the configuration data. Effecting changes to the configuration data, and therefore the distributed databases, includes the steps of first writing the requested change to a master audit log, distributing the change request to all nodes, receiving back from the nodes acknowledgement of the change request being effected at the acknowledging node, and then writing again to the master audit log that the change has been effected throughout the system. The master audit log thereby contains a reliable copy of the configuration data maintained in the database associated with each node of the cluster so that in the event any of the configuration data becomes corrupted, it can be replaced with correct data from the master audit log.		

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5                   A FAULT TOLERANT METHOD OF MAINTAINING AND  
                  DISTRIBUTING CONFIGURATION INFORMATION IN A  
                  DISTRIBUTED PROCESSING SYSTEM

                  BACKGROUND OF THE INVENTION

10               The present invention relates to computing systems of a  
                  type in which multiple processor units are arranged as a  
                  cluster of communicatively interconnected nodes, each node  
                  comprising one or more processor units. In particular, the  
                  invention relates to maintaining and distributing to each node  
15               configuration data identifying particular characteristics of  
                  the cluster and its elements in a fault tolerant manner.

                  In today's industry, there are certain computing  
                  environments, such as stock exchanges, banks,  
20               telecommunications companies, and other mission critical  
                  applications, do not tolerate well even momentary loss of  
                  computing facilities. For this reason such environments have,  
                  for many years, relied on fault tolerant and highly available  
                  computer systems. The architectures of such systems range  
25               from simple hot-standby arrangements (i.e., a back-up computer  
                  system stands ready to take over the tasks of a primary  
                  computer system should it fail) to complex architectures which  
                  employ dedicated (and replicated) portions of the computing  
                  hardware. These latter systems may be most effective in  
30               providing continuous availability, since they have been  
                  designed with the goal of surviving any single point of  
                  hardware failure, but suffer a price premium due to the  
                  increased component cost needed for component replication.  
                  But, even with component replication, the architecture is  
35               still susceptible to a single point of failure: the operating  
                  system. One approach to the problem of a single operating  
                  system is to employ a distributed operating system.

Distributed operating systems allow collections of independent machines, referred to as nodes, to be connected by a communication interconnect, forming a "cluster" which can operate as a single system or as a collection of independent processing resources. The fault tolerance can be provided by incorporating hardware fault detect with the distribution of the operating system in the cluster. High availability is achieved by distributing the system services and providing for takes of a failed node by a backup node. With this approach, the system as a whole can still function even with the loss of one or more of the nodes that make up the cluster. Therefore, the operating system will no longer be a single point of failure. Since the operating system is providing the high availability and fault tolerance, it is no longer necessary to incorporate replicated hardware components to the extent previously used, although their use is not precluded. This can alleviate the price premium of fault tolerant hardware.

Recently, the clustering concept has been extended to computing architectures in which groups of individual processor units form the nodes of the cluster. This approach allows each node, having two or more processor units to operate as a symmetric multiprocessing (SMP) system capable of exploiting the power of multiple processor units through distribution of the operating system and thereby balance the system load of the SMP node. In addition, it may be possible for an SMP configured node can reduce downtime because the operating system of the node can continue to run on remaining processors in the event of failure of one processor.

However, in order to employ multiple SMP nodes in a cluster, and have them able to operate efficiently as a single processing environment, or even that the processors of a node do so, there should be available configuration data that provides a description of the cluster. That description will provide, for example, information such as how many nodes make up the cluster, the composition of each node, the address of each processor unit of a node, the processes running on or

available to the node(s), the users of the cluster and their preferences, and the like. Further, this configuration data should remain consistent, accurate and continuously updated across the cluster members, and herein is introduced areas of attack on the fault tolerant and high availability aspects of the cluster. Improper retention and/or distribution of the configuration data can leave it vulnerable to corruption by viruses, hackers, or even inadvertent, but well-meaning, corruption by a system administrator who makes an erroneous change. In addition, the configuration data should remain consistent across all nodes to allow all cluster members to agree e.g., as to what nodes (and the processor units they contain) are located where. Changes to the configuration data used by one node should also be made to the configuration data of the other nodes. Thus, distribution of such changes must be resistant to faults.

As reliance on computer systems continues to permeate our society, and as more services move on-line, twenty-four by seven operation and accessibility will become critical. Therefore, fault tolerance and high availability are, and will continue to become exceedingly important. Being able to offer the same level of fault tolerance and high availability in software via clustering, as can be achieved with fault tolerant hardware, will be very attractive. Highly available, fault tolerant, and scalable systems will then be able to be created from commodity components and still achieve the same level of reliability and performance as much more costly dedicated fault tolerant (FT) hardware.

#### SUMMARY OF THE INVENTION

The present invention provides a method of maintaining a consistent database of configuration data across the interconnected nodes of a cluster so that the configuration data remains highly reliable and available in the face of all but the most disastrous attacks. Changes to the configuration data, and distribution of those changes, are

handled in a fault tolerant manner so that the configuration data accessible to one node is substantially identical to that of any other node.

5       According to the present invention, each of a number of multiprocessor nodes of a computing system cluster is provided a database or "registry" for containing configuration data. One of the nodes as the residence of a primary process which, among other things not relevant here, has the responsibility  
10 of receiving all requests that require a change to the configuration data in the registry of any of the nodes, and therefore the registries of all the nodes. The primary process maintains a master audit log on a disk storage that is "mirrored." (I.e., an identical copy of the content of the  
15 audit log is kept on a second disk storage unit.) Thus, all requests for a change of the configuration data maintained in the registry received by the cluster are routed to the primary process. When a request for registry change is received by the primary process, information concerning the request is  
20 first written to the master audit log and mirror audit log. Then, the primary process prepares a message containing request data and sends the message to a monitor process running on each node (including that node at which the primary process resides). Each monitor process is responsible for  
25 maintaining and providing access to the registry. Upon receipt of the request data, each monitor process will access the associated registry of that node affecting the indicated change and report back to the primary process that the change of the request was accomplished. Upon receipt by the primary  
30 process of all change reports, it will then write to the master audit log (and mirror audit log) that the requested change is complete. Thereby, all changes to the registry are maintained in the audit log so that a complete copy of the registry is kept by the audit log.

35

In a further embodiment of the invention, nodes of the cluster may be configured to implement the "process pair" technique described in U.S. Pat. No. 4,817,091. According to

this embodiment of the invention, a process of any node can have a backup process on another node somewhere else in the cluster. Failure of the process will result in its backup process in taking over the tasks of the failed process. To ensure that the backup process is able to pick up from as near to the point of failure as possible, "checkpoint" data is sent by a process to its backup so that the backup is kept up-to-date as to the activity of the process it is backing up. These checkpoints are made for significant events (those events that are important to a takeover), or more often if desired.

This process pair technique is employed in connection with the primary process. Thus, when the primary process receives a request to change the configuration data contained in the registry, an indication of that change is "checkpointed" to a backup process for the primary process - before the indication of the request is written to the master audit trail. Should the primary process fail before the change to the configuration data of the registry is complete, the backup process can either complete the change, depending upon where in the operation the failure occurred, or back out of the operation in favor of beginning over again.

It will be apparent to those skilled in this art that the present invention has a number of advantages. Configuration data may now be maintained safe from corruption, and distributed in a fault tolerant, reliable manner. Corruption of any registry of any one node (or even all nodes) can be corrected using the content of the master audit log. In addition, the master audit log is kept updated in a manner that ensures the configuration data's credibility and reliability.

These and other features, aspects, and advantages will become apparent upon a reading of the detailed description of the invention, which should be taken in conjunction with the accompanying drawing.



## BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is simplified block diagram illustration of computing system architecture in the form of a four node cluster;

5 Fig. 2 is a conceptual illustration of the cluster of Fig. 1 to show the steps taken by the present invention; and

10 Fig. 3 is a flow diagram illustration, showing the steps taken by the present invention to maintain a safe and reliable copy of the registry, and to distribute changes to the registry to the nodes of the cluster of Fig. 1 in a fault tolerant manner.

## DESCRIPTION OF THE PREFERRED EMBODIMENT

15

Referring now to the Figures, and for the moment specifically to Fig. 1, there is illustrated a computing system, generally designated with the reference numeral 10, comprising a number (four) of processing nodes 12 (node 0, node 1, ..., node 3) that form a cluster 14. Each processing node 12, in turn, may comprise one or more processor units P. Thus, as Fig. 1 illustrates, node 0, node 1, and node 3 comprise two or more processor units P. Node 2, on the other hand, includes only one. This is for illustrative purposes only, and how many processor units P are used to make up any one node 12 of a cluster is not relevant to the employment of the present invention, although a limit of 8 processor units P for each node may be sufficient. (The cluster 14, on the other hand, may include up to 128 nodes 12.)

30

The limitation of 8 processor units P per node 12 results from the symmetric multiprocessing operating system used for the nodes: Windows NT, which is available from Microsoft Corporation, One Microsoft Way, Redmond, Washington (Windows and Windows NT are trademarks of Microsoft Corporation). Future editions of the Windows NT operating system, or other operating systems, may allow increased numbers of processor units to be included in each node.

35

The nodes are communicatively connected to one another, and to a number of storage elements 16 ( $16_1, 16_2, \dots, 16_n$ ), here represented as disk storage, by a data communication network 15. The communication network 15 preferably is that disclosed in U.S. Pat. No. 5,574,849, the disclosure of which is incorporated by reference to the extent necessary.

In order for each processor unit P to keep information concerning its own configuration (the processes it runs, any special information concerning those processes, special needs of users of those processes), as well as information needed by each of the nodes 12, each node will maintain configuration data in a registry that is kept, for each node, on disk storage. Thus, the registries for node 0, node 1, ..., node 3 are respectively kept on storage units  $16_3, 16_4, 16_5$ , and  $16_n$ , respectively. Each node will have a monitor (MON) process (Fig. 2) whose responsibility is, among other things not relevant here, to access and maintain the registry. Changes and modifications to the respective registries are effected by configuration messages that are sent by a central or primary process to all MON processes, as discussed further below. According to the present invention, all registries are maintained by the respective MON processes of the associated nodes so that they (the registries) are identical.

The system 10 typically can include a number of work stations, or other user (or other) input apparatus, from which transaction requests may be received and responded to as necessary. (As used here, a transaction is an explicitly delimited operation, or set of related operations.) The work station 20 is meant to represent such input apparatus.

One of the nodes 12, for example node 0, is chosen as to the residence node of a primary process with the responsibility of keeping track of the transactions received by the system 10, where they are being handle, and when the transaction is complete. Transaction monitoring is used to ensure that the transaction completes, or if it does not

complete (e.g., because the node/processor/process operating on the transaction fails), the process will either attempt to complete the transaction, or backup out to a point where the transaction can be restarted (e.g., on another  
5 node/processor/process, as the case may be) in an effort to complete. This primary process (hereinafter "Primary Transaction Monitoring Process," or "P-TMP") is also assigned the responsibility of receiving all indications ("requests") that will require a change to the registries of the system 10.  
10 (For example, registry changes may be necessitated by addition or removal of nodes to or from the system 10, or changes in other configuration aspects.) This helps ensure that the configuration data contained in the registries associated with all nodes 12 remains consistent and substantially identical  
15 for those reasons stated above. In addition, the P-TMP will also be responsible for keeping a copy of the configuration data in a safe repository, here a master audit log or master audit log ("MAT") that is retained by disk storage unit 16.  
20 Of course, the master audit log may also keep other important information that, like the configuration data, needs to be copied so that in the event such information is corrupted, lost, or otherwise rendered suspect, it can be recreated and replaced from the copy. (A discussion of an audit log may be found in U.S. Pat. No. 5,590,275.) A mirrored copy of the  
25 MAT, MAT', is kept on a separate storage facility: disk storage unit 16z.

Turning now to Fig. 2, the nodes of the system 10 (Fig. 1) are shown in a conceptual form to represent the processes  
30 used for the present invention, and their interrelation to implement the invention. Fig. 3 broadly illustrates, in flow diagram form, the operations of the invention.

Referring first, however, to Fig. 2, shown, as indicated  
35 above the P-TMP installed and running on the SMP environment provided by the processor units P of node 0. Its backup, B-TMP, is installed on node 2, although any other node (except, preferably, node 0) may be used to accommodate B-TMP. In

addition, the monitor process (MON) is installed on each of the nodes 12 which, among its various tasks, is the responsibility of accessing, maintaining, and modifying the registry for the (REG) associated node 12.

5

Fig. 3 diagrammatically illustrates the steps taken to modify the registry associated with each of the nodes. It will be appreciated, that the actual communication between processor units P (not shown in Fig. 2) of each node 12 is via an internal database 13. And, communication between a process operating on that node (e.g., one of the processor units P) and any other process in the system 10, or the storage elements 16, will be conducted with the aegis of the communications network 15. Thus, for example, although the P-TMP is shown with communication paths to the disk storage units 16, and 16z whereat the MAT and its mirrors, are kept. In addition, the communications network 15 provides the medium for allowing the P-TMP to communicate with MAT' B-TMP on node 2, or the MON processes of the nodes 12. Similarly, the MON processes of each node 12 communicate with their associated registry (REG) also through the communications network 15. Preferably, the communications network 15 will take the form of that shown in U.S. Pat. No. 5,574,849, although those skilled in this art will readily see that other forms of communication networks may be used.

Referring now to Fig. 3, and taking it in conjunction with Fig. 2, the steps for updating the configuration data maintained by the registries REG will now be described. Assume that the system 10 receives an indication that the configuration of that system changes. For example, a new user logs onto the system 10 from the workstation 20 (Fig. 1) to use a process installed on node 3. The presence of a new user, and the process(es) that will be employed by that user, and other information, are matters pertaining to the configuration of the system, and kept in the configuration data of the system registry (i.e., the registries maintained by each node 12). The configuration data maintained by the

registries must be updated to account for the new user, the workstation being used, the process(es) invoked, and any other additional information needed by the nodes 12. The particulars concerning the new user will be routed to the P-TMP as shown by the flow diagram 30 at step 32.

When received the information by the P-TMP, it will first transmit a communication to the B-TMP on node 2 with information indicative of the fact that a change of the configuration data has been, in effect, requested together with the required information. The reason for this is that if the P-TMP fails during the change operation, the B-TMP, using the information concerning the change, can either continue the change operation until completion, or back it up and start over, when it takes over for the failed P-TMP.

Next, after the "checkpoint" operation to B-TMP, step 38 sees the P-TMP writing the indication of configuration data change to the MAT (step 38). The process (a disk process) that writes the information to the MAT will also write that same information to the mirrored volume retaining the MAT'. If P-TMP fails, and the B-TMP is required to take over, B-TMP can retrieve information from the MAT in order to determine how best to proceed with the change (i.e., to continue, or to back-out).

The P-TMP continues at step 40 by distributing the registry changes to each of the MON's of each of the nodes, including the node 0 on which P-TMP is mounted. A software timer is then set by the P-TMP, and after the registry change requests are sent to the MONs (step 40), the P-TMP will wait for acknowledgements that the change request was received by each of the MONs. In the event any particular MON process encounters an error in attempting to write its associated registry REG, the MON process will issue a "poison pill" message to the processors of that particular node to shut the node down so that no data errors are propagated from the node to the rest of the nodes of the cluster.

Preferably, the system 10 utilizes a form "I'm alive" concept in which each node periodically transmits to all other nodes a message indicative of that node's continuing good health. If an I'm Alive message is not received from a node, by the remaining nodes, that node is considered to have failed, or have been removed, and the P-TMP will be informed accordingly so that it can formulate a registry modification that will indicate the absence of the failed/removed node. (The absence of an I'm Alive message from a node will be noted by those backup processes, if any, that have or had associated primary processes on the failed node. The lack of an I'm Alive message will prompt those backup processes to spring into action to take over the tasks of the corresponding primary processes that were on the now-silent node.) That registry modification is then checkpointed to the B-TMP (assuming that it is not the failed node), written to the MAT (and the mirror MAT, MAT'), and distributed to the nodes remaining in the system, in the manner described above.

In an embodiment of this invention, each of the nodes 12 will have installed and running a cluster manager (CM) process (not shown) responsible for keeping track of what nodes are in the system, what processor units are in what nodes, etc. There is a CM on each node continually communicating with the CMs of the other nodes, and all communications sent require a reply. In view of this frequency of messaging between all nodes, it is believed unnecessary to add to the communication traffic carried by the network 15. Thus, when the CM of any node 12 realizes that it has not heard from the CM of any other node (e.g., node 12<sub>2</sub>, Fig. 1) within a predetermined period of time, it will declare that node "dead," and communicate that declaration to the remaining nodes (i.e., their CMs). This achieves the same result as the "I'm Alive" transmissions, but at less expense to overall system and node performance.

WHAT IS CLAIMED IS:

1. A method of maintaining a consistent, fault tolerant database of configuration data in each of a number of processor units communicatively intercoupled to form a multiple processor system, the database of configuration data maintained by each of the number of processor units being substantially identical, including the steps of:
  - receiving a request to modify the database at a one of the number of processor units;
  - the one processor unit operating to write the information corresponding to the request data to a master audit trail file,
  - send a modify message corresponding to the request to the number of processor units, and
  - each of the number of processor units effecting the modification as indicated in the modify message.
2. The method of claim 1, wherein another of the number of processor units serves as a backup processor, and including the step of the one processor unit operating to send a data message to the backup processor unit with information corresponding to the request data.
3. The method of claim 2, wherein the step of operating to send a data message to the backup processor unit occurs before the step of operating to write the information.
4. In a multiple processor system of a type including a number of processor nodes, each processor node comprising one or more processor units interconnected to form a symmetric multiple processing system, the multiple processor system from time to time receiving requests that require changes to the configuration data, a method of maintaining a consistent, fault tolerant database of configuration data for each of the number of processor nodes, including the steps of:

10 providing each of the number of processor nodes with  
a monitor process responsible for maintaining a copy of the  
database of configuration data for such node;  
designating a one of the number of processor nodes  
to give residence to a primary process that operates to,  
receive all requests requiring a change or  
15 modification of the configuration data,  
writing an indication of the change to be  
effected to a master log,  
sending data messages to each of the monitor  
processes indicative of the change to the  
20 configurations data;  
each of the monitor processes receiving the data  
messages to effect changes in the configuration data contained  
in the associated database of configuration and data and  
sending an acknowledgement message that the change to the  
25 database of configuration data is complete.

5. The method of claim 4, including the step of the  
primary process operating to receive the acknowledgement  
messages from the monitor process of each of the number of  
processor nodes, and writing an indication to the master log  
that the change is complete.



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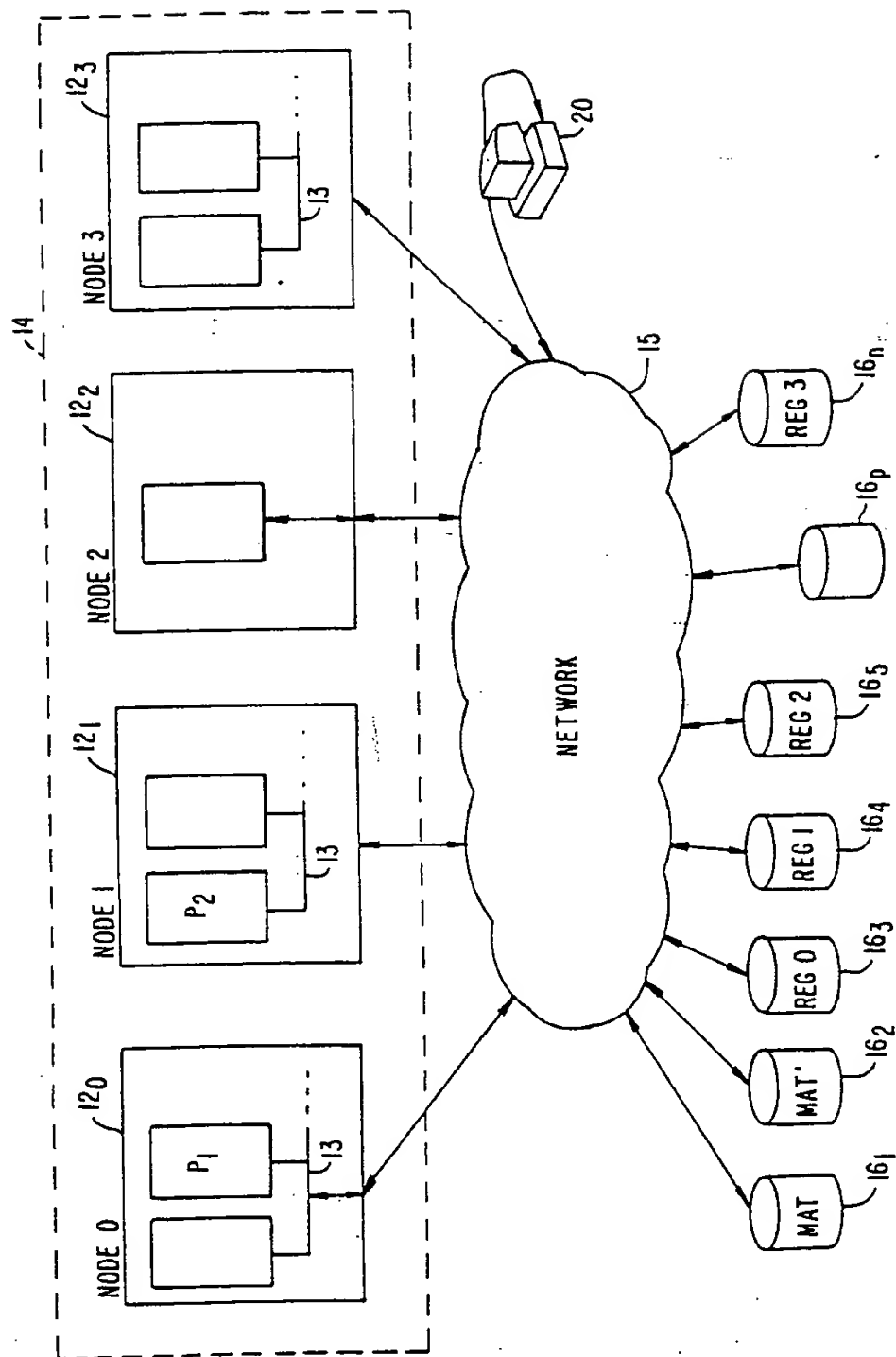


FIG. 1.

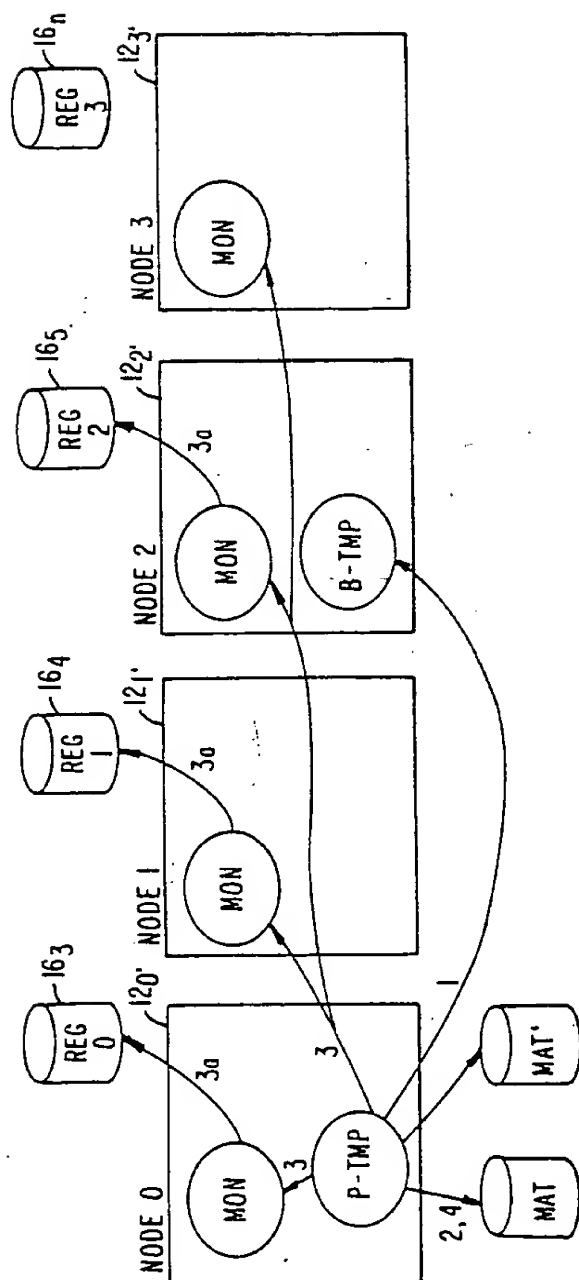


FIG. 2.

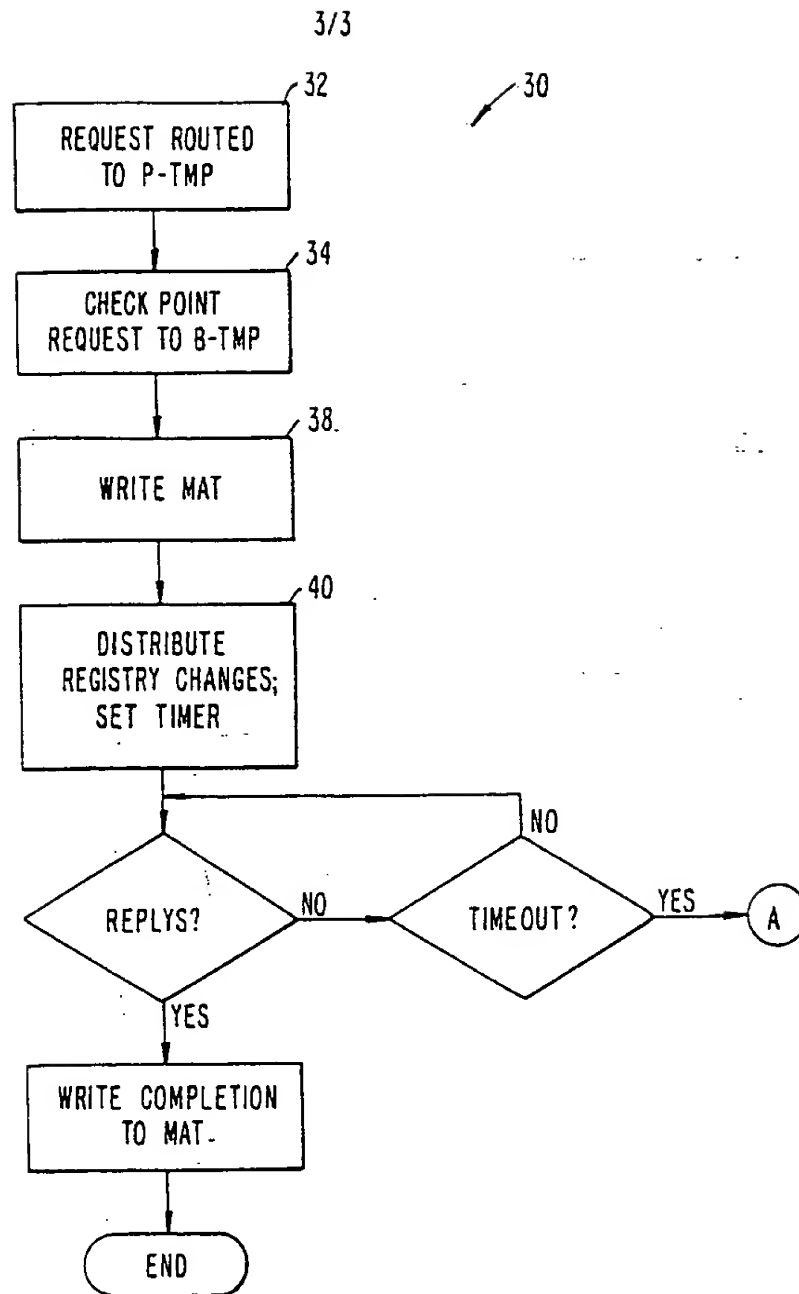


FIG. 3.

# INTERNATIONAL SEARCH REPORT

In: ational Application No

PCT/US 98/20415

A. CLASSIFICATION OF SUBJECT MATTER  
IPC 6 G06F11/14

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 G06F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0 772 126 A (SUN MICROSYSTEMS, INC.) 7 May 1997 see column 9, line 1 - column 10, line 32 ---	1,4,5
A	EP 0 723 227 A (TANDEM COMPUTERS INCORPORATED) 24 July 1996 see column 2, line 40 - column 3, line 2 -----	2,3

☐ Further documents are listed in the continuation of box C.



Patent family members are listed in annex.

### \* Special categories of cited documents:

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Date of the actual completion of the international search

5 March 1999

Date of mailing of the international search report

15/03/1999

Name and mailing address of the ISA

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# INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/US 98/20415

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
EP 772126	A	07-05-1997	EP 0801746 A	22-10-1997
			JP 9237226 A	09-09-1997
			WO 9716744 A	09-05-1997
<hr/>				
EP 723227	A	24-07-1996	CA 2167634 A	24-07-1996
			JP 9026891 A	28-01-1997
			US 5828569 A	27-10-1998
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